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Mechanical properties of paste carburized ASTM A516 steel

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Abstract

Carburizing is one of case hardening method that induced formation of carbon layer on the surface of a substance in order to improve the strength and hardness properties. This paper presents the effect of paste carburizing treatment on mechanical properties of ASTM A516 low carbon steel. Samples are first prepared and polished according to tensile test (ASTM A370), hardness test (Rockwell) and microstructure standard. The paste carburizing treatment was conducted at temperature of 700°C, 750°C and 800°C for 6 hours holding times. The results depicted that paste carburized samples provide significant improvement on both tensile strength and hardness values compared to uncarburized samples. This was associated with the formation of hard carburized layer on the surface of the substance. Increasing the carburizing temperature profoundly improved both hardness and tensile strength, as the results of deeper carburized layer produced. Paste carburizing was found to induce formation of carburized layer at shorter time and lower temperature compared to pack carburizing method.

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Keywords: ASTM A516 Steel ; mechanical properties ; paste carburizing treatment

1. Introductions

These days, low carbon steels had been extensively used in numerous applications due to their high availability and cost considerations. This can be proven by looking at the variety of applications being manufactured using low carbon steels as in the field of buildings, transportation, and machines. Unfortunately, there are some margins in the properties of low carbon steels that restricted the usage of low carbon steel at modern manufacturing process. For an instance, the carbon contains for low carbon steel are approximately in between 0.15% to 0.45% which makes the surface hardness of low carbon steel is poor compared to other type of steel. Moreover, it is neither externally brittle nor ductile and has lower tensile strength and malleable due to its low carbon content. As the carbon content increases, the metal becomes harder and stronger but less ductile and more difficult to be weld in such of application as the railways wheels, gear teeth profile, crane wheels, crane cable drum, gear wheel, pinion blanks and brake drum. In many engineering applications, it is desirable that steel being used should have a hardened surface to resist wear and tear [1]. Nevertheless, today the problem related with surface hardness that lowered the mechanical properties of low carbon steel can still be recovered by using heat treatment process. This study shows technological

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progress in steels heat treatments which is paste carburizing in the case of hardening that will give a result in changing the microstructure and improvement in mechanical properties of low carbon steel. Thus, the main attentive of this study is to explore the influence carburizing temperature to time on the microstructure and mechanical properties of carburized low carbon steels.

It is important that sufficient carburizing layer was produced on the surface of the substance with the thickness up to 0.3 inch in order to induce significant improvement on the properties of carbon steel. Past studies indicated that carburizing in pack or powder medium had successfully enhanced the properties of various types of steels especially in low carbon steel. In pack carburizing, samples are heated at temperature ranging from 850°C to 1050°C for 8 to 12 hour holding times [2-4]. Past researchers studied on the pack carburizing of different types of carbon steel, under different types of cooling medium at temperature in between ranging from 850°C to 977°C. Samples were then quenched in oil and tempered at 550°C and the mechanical properties were evaluated [5-6]. Fatai Olufemi et. al. 2010 observed that the mechanical properties of mild steels strongly influenced by the process of carburization, carburizing temperature and soaking time at carburizing temperature as the sample carburized at 900°C, oil quenched and tempered at 550°C had better engineering strain, impact strength, ultimate tensile strength and Young's modulus because they indicated a trend of hard case with softer core [5]. It was also stated that the differences in the cooling rate appear to provide dramatic effects on the micro hardness of steels depending on the carbon content of steels [6]. Due to solid solution hardening and formation of the martensite phase, the micro hardness increases with increasing cooling rate and carbon content. It was observed that plain carbon steel exhibited the maximum carbon uptake. It was also evaluated that the carbon concentrations profile in the alloy steels were lower than in the plain carbon steel depends on the level of alloying and on the nature of carbon and alloying elements [7]. This signify that the properties of low carbon steel can be easily enhanced compared to alloyed steels. Although pack carburizing treatment was affordable and simple to execute, the limitation of this process are longer carburizing time and higher carburizing temperature are needed to induce deeper carbon layer on the surface of the substances. It would be beneficial if carburizing treatment could be conducted at shorter time and lower temperature for cost effective reasons. Thus, this study concentrate on using paste as the carburizing medium in order to promote the formation of carbon layer at shorter and

2. Research Methodology

2.1. Mechanical testing and microstructure observations.

In this study, mechanical properties of both carburized and uncarburized samples were evaluated through tensile test in accordance to ASTM A370 standard and Rockwell hardness test implying HRB scales with 10 indentations taken. Samples were first cut using an abrasive cutter and machined according to the standard above. The surface was then polished with diamond paste to obtain smooth surface finish. The sample for microstructure was prepared according to metallographic standard which involved cutting using abrasive cutter, hot mounting, grinding with abrasive paper grade 180μm to 1200μm and polished using 6μm, 3μm and 1μm diamond paste. Samples were then observed using Olympus BX 41M microscope. The existences of carbon layer were then validated though Rigaku X-Ray Diffraction (XRD) diffractometer with 2θ angle between 30 to 120° using CuKα radiation. All tests were conducted at room temperature. Table 1 shows the compositions of ASTM A316

2.2. Carburizing treatment

In order to initiate the formation of carbon layer on the surface of low carbon steel, paste carburizing treatment was conducted. Sodium Carbonate, Barium Carbonate and water are mixed together to form the carburizing paste. Samples were then coated with the carburizing paste and placed inside a tightly close chamber. Samples were heated inside an induction furnace at 3 different temperatures which were 700°C, 750°C and 800°C for 6 hours holding times before let cooled inside the furnace.

3. Experimental Results

3.1. Chemical Compositions

Table 1 shows the compositions of ASTM A316 steel, obtained through Arc Spark SpecroMaxx spectrometer.

Table 1. Chemical compositions of ASTM A316 steel

Chemical Compositions (wt%)	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	V	Fe
	0.19	0.15	0.06	0.046	0.58	0.13	0.11	0.016	0.384	0.001	98.25

3.2. Microstructure observations

Fig 1 shows the microstructure observations of (a) uncarburized and carburized samples at (b) 700°C, (c) 750°C and (d) 800°C. It could be seen in Fig 1 (a) that uncarburized samples consist of ferrite in and pearlite phases, verified through XRD analysis at 2θ angle of 43º, 65 º and 82 º for ferrite phase and 44º, 65 º and 82 º for pearlite phases. Fig 1(b) shows the microstructure observations of carburized samples at 700°C showing presences of carbon layer on the surface of the substance. It is shown that the carburized layer with slow cooling down rate of furnace cooling consist of 3 zones: (1) a thin hyper-eutectoid zone (about 0.8–0.9% carbon) near the outer surface; (2) an eutectoid zone (about 0.7– 0.8% carbon) and (3) a hypo-eutectoid zone (0.7–0.2% carbon), in comparison with past literature (D.C. Lou, 2009). The presences of carbon in the carburized samples are validated through XRD analysis at 2θ angle of 43º, 56 º and 60 º, shown in Fig 2. Higher carburizing temperature will form deeper layer of carbon penetrate which slightly will also increased the hardness low carbon steel. This could be seen in Fig 1 (c) and (d). In the past research reported by Sanjib Kumar Jaypuria, 2008 indicated that such deeper carburized layers or a case depth can be increased by increased exponentially in carburization temperatures and longer cycle of carburization process [1]. In addition, Daniela Dragomir, 2001 from the past research shows a similar result in the carburizing process microstructure which form deeper carbon layer at the carburizing temperature of 950 ºC [8]. In comparison to past literature, the formation of carbon layer could be achieved at shorter time of 6 hours instead of 8 hours and at temperature of 700°C instead of 850°C. The results for carbon layer dispersion are shown in Fig 3.

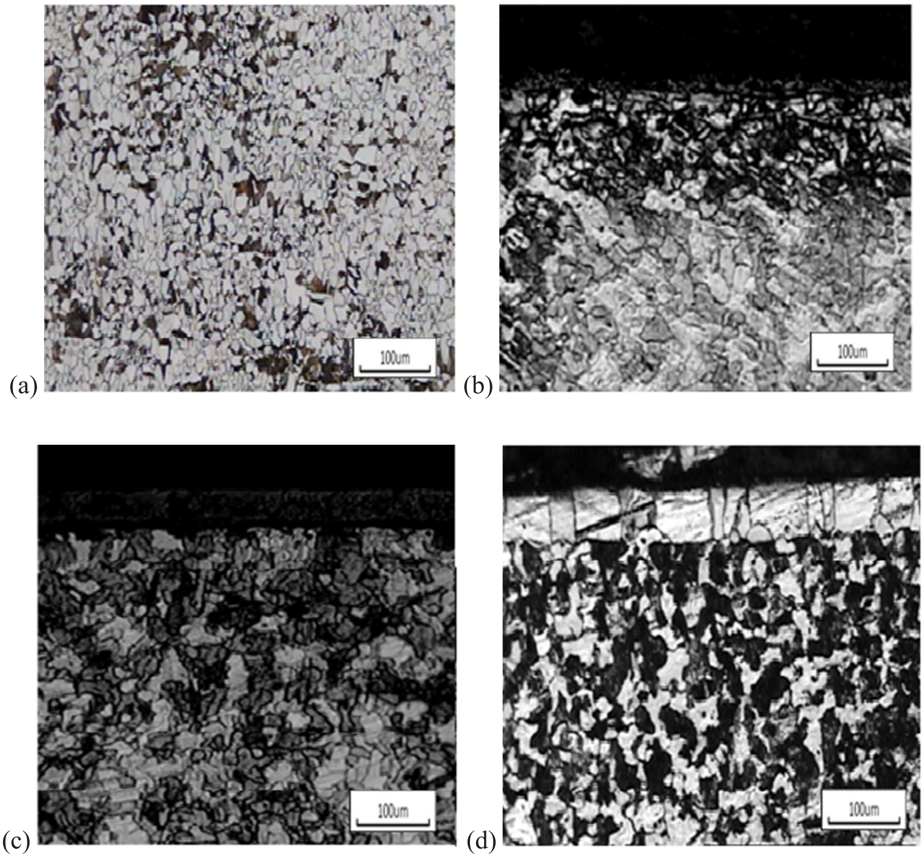

Fig. 1. Microstructure observations of (a) uncarburized and carburized samples at (b) 700°C, (c) 750°C and (d) 800°C.

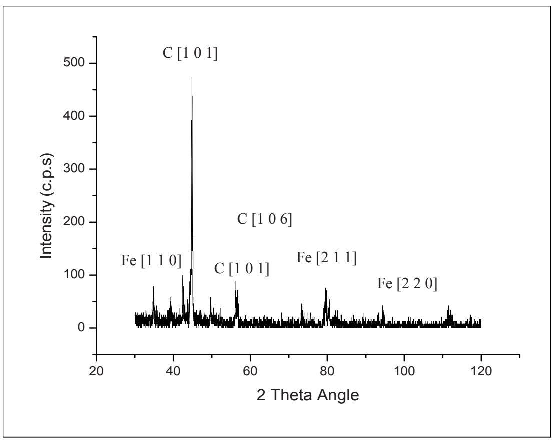

Fig. 2. XRD analysis of paste carburized sample

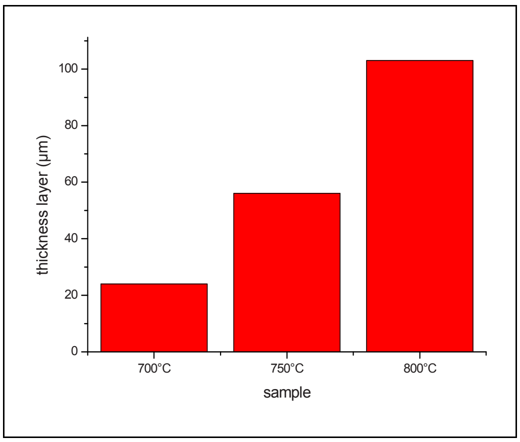

Fig. 3. Thickness layer of paste carburized sample.

3.3. Mechanical properties

The relationship between tensile strength and carburizing temperature is shown in Fig 4. It could be seen that carburizing treatment had superiorly improved the tensile strength values due to the formation of carbon layer on the surface of low carbon steel samples. Increasing the carburizing temperature had further improved the strength of the samples as deeper carburizing temperatures are produced. In comparison, B. Eghbali et. al. 2005 also reported that there is a close relation in term of the microstructures and true stress-true strain responses during the deformation by higher carburizing process temperature [9]. The same situation also highlighted by past research that in the case carbon content, the result show that process time and temperature affected the yield strength, ultimate strength and percentage of elongation [10].

Fig 5 shows the hardness values of both uncarburized and carburized samples. Similar to the trend observed in tensile strength values, it could be seen that carburizing provided favorable effect on hardness properties as hard carbon casing are produced on outer layer surface of the samples. The highest hardness values are obtained by samples carburized at 800°C, having the optimum thickness layer. This was comparable with the studies conducted previously which indicated that the greater the temperature and time, the higher the value of the hardness [1].

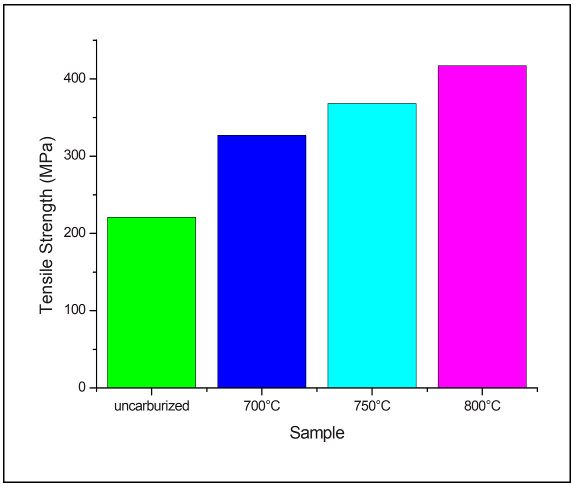

Fig. 4. Tensile strength of all types of sample

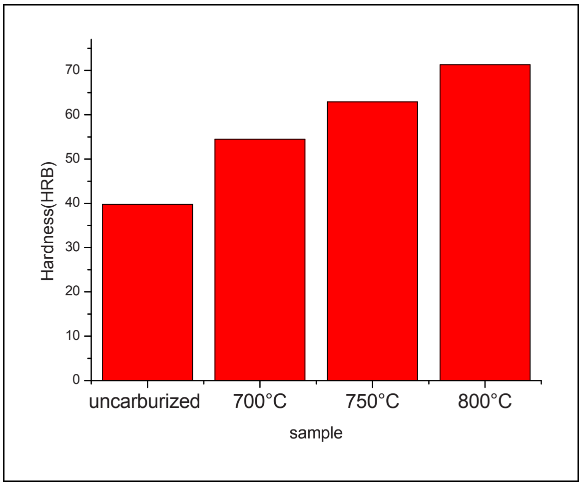

Fig. 5. Hardness of all types of sample

4. Conclusions

The following conclusions could be derived from this study

- Paste carburizing method had produced thick carbon dispersion layer with thickness of 23 to 105 μm in relation with increment of carburizing temperatures.
- It was also found that paste carburizing treatment had improved both tensile strength and hardness properties as compared to uncarburized samples, due to formation of hard carburized layer.
- Increment of carburizing temperature was found to further improve the tensile strength and hardness values, with respect to deeper carburized layer produced.

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